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# Mineral Nutrition of Cotton Fertilized with Poultry Litter or Ammonium Nitrate

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## ABSTRACT

**Poultry litter is a superior fertilizer for cotton (*Gossypium hirsutum* L.) production in some soils, but whether this superiority is related with its ability to supply multiple mineral nutrients has not been well investigated in the field. The objective of this research was to determine if the yield increasing effect of litter relative to inorganic N fertilizers may be related with better mineral nutrition and to compare the nutrient profile of litter- and inorganic N-fertilized cotton. Cotton was fertilized with six broiler litter rates ranging from 2.2 to 13.4 Mg ha$^{-1}$ or six $NH_4NO_3$–N rates ranging from 34 to 168 kg ha$^{-1}$ plus an unfertilized control (UTC) in northern Mississippi in a silt loam upland soil. Fertilizing with litter resulted in greater concentration of extractable soil P, K, Ca, Mg, Cu, Zn, and Na than fertilizing with $NH_4NO_3$, but these increases did not always result in greater concentrations of these elements in aboveground plant parts. Only concentrations of K, B, and Na were increased by litter in plant parts. The two fertilizers had the same effect on soil Mn concentration, but $NH_4NO_3$, relative to litter, elevated Mn concentration in plant parts by as much as twofold, a result that seemed to be related to soil pH decline. The results suggest that the better yield performance of fertilizing cotton with poultry litter than with $NH_4NO_3$–N in this soil may have been due to a more ideal soil pH, favorable tissue Mn concentration, and improved K and B nutrition.**


Poultry litter, which is composed of manure and one of several bedding materials, is generated as a byproduct of the chicken (*Gallus gallus*) or turkey (*Meleagris gallopavo*) production industry. Poultry litter contains many of the plant nutrients and therefore is land-applied as a fertilizer and as a way of environmentally acceptable waste management.

Poultry litter has proven to be an effective fertilizer for agronomic and horticultural crops (Demir et al., 2010; Sistani et al., 2008; Tewolde et al., 2008), forage and pasture crops (McGrath et al., 2010; Sistani et al., 2004), and for forest and other trees (Blazier et al., 2008; Friend et al., 2006). In the southern and southeastern United States, much of the litter generated in the region is applied to forage and pasture fields, but an increasing amount also is applied to row crops, partly because new research in the past 10 yr has shown the benefit of using litter for cotton and other row crop production.

In the upland soils of the southern and southeastern United States, research has shown that fertilizing cotton with poultry litter often results in increased lint yield relative to fertilizing with single-nutrient synthetic fertilizers (Endale et al., 2002; Reddy et al., 2007; Tewolde et al., 2008; Tewolde et al., 2009). In an Atwood silt loam soil (fine-silty, mixed, semiactive, thermic Typic Paleudalfs) in northern Mississippi, broiler litter increased cotton lint yield by 10% under conventional till and by 14% under no-till relative to the standard local fertilization with inorganic fertilizers although litter supplied the same amount of plant available N as the standard local fertilization (Tewolde et al., 2008). In the Black Belt Prairie clay soils of Mississippi, fertilizing cotton with high rates of broiler litter increased cotton lint yield by as much as 26% above that of the local recommendation with conventional fertilizers (Tewolde et al., 2009). On a Decatur silt loam soil (fine, kaolinitic, thermic Rhodic Paleudults) in Alabama, Reddy et al. (2007) found a 5-yr average lint yield increase of about 7% if cotton was fertilized with fresh poultry litter relative to that fertilized with urea. In Georgia on a Cecil sandy loam soil (fine, kaolinitic, thermic Typic Kanhapludults), Endale et al. (2002) showed that no-till cotton yield was better when fertilized with poultry litter than with conventional inorganic fertilizers although the differences were not always significant.

This superiority of litter to synthetic fertilizers for cotton production may be related to the ability of litter to supply many of the essential metal and other mineral nutrients in addition to the usual N, P, and K. Whether the better yield performance of cotton fertilized with poultry litter in some soils is due to better mineral nutrition is not well investigated. Further, the mineral nutrient profile of cotton fertilized with broiler litter vs. conventional inorganic fertilizer with rates that range between deficient to sufficient to excess is not well documented. Comparisons of litter-fertilized cotton against cotton fertilized with a selected rate of synthetic fertilizers have been reported. But, while such comparisons are useful, a greater understanding of the contribution of litter-derived mineral nutrients to lint yield may be gained when comparing

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**Abbreviations**: DAP, days after planting; ICP, inductively coupled plasma spectrophotometer; UTC, unfertilized control.

fertilization rates of both manures and synthetic fertilizers that range between deficient to sufficient to excess for optimal lint yield. The objectives of this research were to compare the mineral nutrient profile of cotton fertilized with selected rates of poultry litter vs. ammonium nitrate and determine if the yield increasing effect of litter relative to that of inorganic N may be related with better mineral nutrition of the cotton plant. Other aspects of this research including lint yield, litter value analysis, soil pH and extractable P and K were published by Tewolde et al. (2010) and Adeli et al. (2010).

## MATERIALS AND METHODS

The research was conducted at the Mississippi Agricultural and Forestry Experiment Station of Mississippi State University, North Branch near Holly Springs, MS in 2002 and 2003 in a Loring silt loam (fine-silty, mixed, active, thermic Oxyaquic Fragiudalfs) soil. This upland soil had ≈1.8% organic matter and 5.6 pH (1:1 soil/water).

### Treatments and Experimental Design

The treatments consisted of fertilization with fresh broiler litter at 2.2, 4.5, 5.6, 6.7, 10.1, or 13.4 Mg ha$^{-1}$ yr$^{-1}$ or with $NH_4NO_3$ (34% N) at 34, 67, 90, 112, 135, or 168 kg N ha$^{-1}$ yr$^{-1}$. An unfertilized control treatment (UTC) was included for a total of 13 treatments. All six $NH_4NO_3$ treatments received a blanket application of 39 kg P ha$^{-1}$ yr$^{-1}$ as triple superphosphate and 112 kg K ha$^{-1}$ in 2002 and 84 kg K ha$^{-1}$ in 2003 as KCl following Mississippi State University Soil Testing Laboratory recommendations. The treatments which consisted of two fertilizer types (litter and $NH_4NO_3$) at six rates each plus the UTC were tested in a randomized complete block design with four blocks repeated in the same plots for 2 yr. Each plot had eight rows spaced 0.97 m apart and was 15.2 m long.

Litter in 2002 was applied by spreading a weighed amount on the soil surface by hand. In 2003, a calibrated amount was applied with a small-plot spreader equipped with a system that controlled application rate and dispensed the litter evenly across a 1.8-m swath. These applications were made on 18 Apr. 2002 and 28 May 2003. A local broiler chicken producer in northern Mississippi supplied the litter each of the 2 yr.

The $NH_4NO_3$, triple superphosphate, and KCl fertilizers were applied by hand to each plot within 2 d of litter application. Following the application of all treatments, the entire field was disked to ≈0.15-m depth before beds were formed on 19 Apr. 2002 and 30 May 2003. This operation served as the method of incorporating the litter and the inorganic fertilizers to the soil.

### Plant Sampling and Analysis

Cotton cultivars 'Sure-Grow 215 BG/RR' in 2002 and 'DPL 215 BG/RR' in 2003 were planted on 12 May 2002 and 2 June 2003. In 2002, the cotton was replanted on 23 May 2002 due to rain-caused soil crusting and subsequent poor seedling emergence.

Mineral nutrient concentrations in plants was determined based on four whole plant samples taken mid-season (62 d after planting, DAP, in 2002 and 78 DAP in 2003). The plants were cut at soil level and separated into leaves (petiole + blade), stems (branch + main stem), and reproductive parts (squares + flowers + bolls). The plant parts were dried in a forced-air oven at 80°C to a constant weight and ground to pass a 1-mm sieve. Concentrations of selected mineral nutrients in the plant parts were determined using an inductively coupled dual axial Argon plasma spectrophotometer (ICP, Thermo Jarrell-Ash Model 1000, Franklin, MA) after ashing approximately 0.2 g of the dried and ground sample in a muffle furnace at 500°C for 4 h. The ash was digested in 1.0 mL 6 M HCl for 1 h followed by 40 mL of a double-acid solution of 0.0125 M $H_2SO_4$ and 0.05 M HCl for an additional 1 h. The digested solution was then filtered using 2V Whatman filter paper and analyzed for concentrations of P, K, Ca, Mg, B, Fe, Cu, Mn, and Zn by the ICP. Concentration of B was measured in 2003 only. Concentration of the same nutrients in litter (Table 1) was determined by the same method used for plant parts. Total N and C in litter (Table 1) was determined by an automated dry combustion method using a ThermoQuest (CE Elantec, Inc., Lakewood, NJ) C/N analyzer.

**Table 1. Chemical properties of soil and fresh broiler litter and amount of mineral nutrients applied to cotton in an experiment that compared litter to inorganic fertilization near Holly Springs, MS.**

| | | | Moisture and mineral nutrient content | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample | Year | pH | Moisture | Total C | Total N | P | K | Ca | Mg | B | Fe | Cu | Zn |
| | | | g kg$^{-1}$ | | | | | | | mg kg$^{-1}$ | | | |
| Soil | 2002 | 5.63 | — | 10.6 | 1.14 | 0.069 | 0.23 | — | — | — | — | 1.09 | 1.82 |
| Litter | 2002 | 7.0 | 187 | 270 | 27.4 | 12.4 | 19.3 | 21.2 | 4.2 | 42 | 1857 | 361 | 329 |
| | 2003 | 7.2 | 187 | 313 | 28.1 | 15.3 | 27.9 | 26.2 | 5.9 | 42 | 1141 | 495 | 419 |
| Applied litter | | | | Total litter-derived nutrients applied to soil | | | | | | | | | |
| Mg ha$^{-1}$ | | | | kg ha$^{-1}$ yr$^{-1}$ | | | | | | | | | |
| 2.2 | — | — | — | 689 | 62 | 34 | 61 | 58 | 13 | 0.09 | 2.51 | 1.09 | 0.92 |
| 4.5 | — | — | — | 1409 | 126 | 69 | 126 | 118 | 27 | 0.19 | 5.13 | 2.23 | 1.89 |
| 5.6 | — | — | — | 1753 | 157 | 86 | 156 | 147 | 33 | 0.24 | 6.39 | 2.77 | 2.35 |
| 6.7 | — | — | — | 2097 | 188 | 103 | 187 | 176 | 40 | 0.28 | 7.64 | 3.32 | 2.81 |
| 10.1 | — | — | — | 3161 | 284 | 155 | 282 | 265 | 60 | 0.42 | 11.52 | 5.00 | 4.23 |
| 13.5 | — | — | — | 4226 | 379 | 207 | 377 | 354 | 80 | 0.57 | 15.40 | 6.68 | 5.66 |

### Soil Sampling and Analysis

Soil samples were taken from the middle six rows of each plot on 5 Nov. 2003 after harvesting the cotton. Four 2.5-cm diam. core samples were taken from 0- to 15-cm depth, composited, air dried, crushed to pass through a 2-mm sieve, and stored at room temperature until analyzed. In addition to the chemical properties reported by Adeli et al. (2010), each sample was also analyzed for extractable Ca, Mg, Mn, Fe, Cu, and Zn by ICP after extracting ≈2 g of the air-dried and crushed soil sample with 10 mL Mehlich 3 extractant.

### Data Analysis

The data were analyzed statistically using PROC MIXED program of SAS (Littell et al., 2002). The data were first subjected to analysis of variance to test if the effects of the 13 treatments, years, and the interactions of treatments with years were significant. The analysis combined across years was performed with years as a repeated measure subunit. The fertilization treatments and years were fixed effect factors and block a random effect factor. The data were then subjected to a further analysis to test the linear and quadratic trends of each fertilization treatment (litter and $NH_4NO_3$–N) effects. The data were subjected to additional testing where the treatment effect was modeled as two fertilizers types (litter or $NH_4NO_3$) and rates within each fertilizer type was treated as covariate using a linear or quadratic trend. Each rate of the litter or $NH_4NO_3$–N treatment was compared against the untreated control by paired *t* test. A group comparison by orthogonal contrast of all litter rates against all $NH_4NO_3$–N rates also was performed. All differences are significant at $P \le 0.05$ unless stated otherwise.

## RESULTS AND DISCUSSION

As recently reported, fertilizing cotton with broiler litter in this soil resulted in greater lint yield than fertilizing with $NH_4NO_3$ at all levels of application (Tewolde et al., 2010). The better yield performance of the litter-fertilized cotton than the $NH_4NO_3$–fertilized cotton was not because of better N nutrition of the litter-fertilized cotton. Actually, litter-fertilized cotton had less bulk leaf N concentration than $NH_4NO_3$–fertilized cotton (Tewolde et al., 2010). The better yield performance of litter-fertilized cotton than $NH_4NO_3$–fertilized cotton may therefore be associated with other mineral nutrients than N and other litter benefits as the two fertilizers had distinct effects on concentrations of some nutrients in the soil and aboveground plant parts.

### Concentration of Extractable Soil Nutrients

The two fertilizer types significantly differed in extractable soil nutrients at the end of the 2003 season. Soil that received litter had greater concentration of extractable Ca, Mg, Cu, Zn, and Na than soil fertilized with $NH_4NO_3$ (Table 2). Earlier, Adeli et al. (2010) reported that soil that received litter had greater concentration of extractable K and P, higher pH, lower bulk density, and greater aggregate stability than soil fertilized with $NH_4NO_3$. The greater extractable mineral nutrient concentration in the soil that received litter was expected because litter supplied additional nutrients (Table 1), while soil pH may also have played a role by altering nutrient extractability.

Increasing rates of the two fertilizers also had different effects on the concentration of extractable nutrients and, as reported by Adeli et al. (2010), on soil pH. Concentration of extractable Cu and Zn clearly increased with increasing litter rate suggesting that these nutrients accumulated in the soil in proportion to the rate applied up to 10.1 Mg ha$^{-1}$ (Table 2). Extractable soil Mg and Na also increased, although less drastically than Cu or Zn, with increasing applied litter rate. The slight increasing trend of extractable soil Ca with increasing litter rate was not significant. Extractable soil Fe was highest and extractable Mn was lowest at the highest litter rates but none of the linear or quadratic trends were significant.

The response of extractable soil nutrients to increasing rates of applied $NH_4NO_3$–N was not as clear as that of applied litter rate. Concentration of many of the soil nutrients including Ca, Mg, Fe, Zn, and Cu were highest when 67 to 112 kg ha$^{-1}$ $NH_4NO_3$–N was applied and declined with higher rates of $NH_4NO_3$–N application, but the linear or quadratic trends were not significant (Table 2). The reverse was true for extractable soil Mn, which declined with increasing $NH_4NO_3$–N rates to the lowest of 177 mg kg$^{-1}$ at 90 kg ha$^{-1}$ $NH_4NO_3$–N but increased to the level of the UTC with the largest $NH_4NO_3$–N rate. Extractable Mn of soil fertilized with any of the $NH_4NO_3$–N rates never substantially exceeded the level of the UTC suggesting that, relative to the UTC, application of $NH_4NO_3$ either reduced or maintained the level of availability of soil Mn. Soil pH declined with increasing application rate of $NH_4NO_3$–N but increased with increasing litter rate (Adeli et al., 2010).

### Concentration of Nutrients in Aboveground Plant Parts

#### Manganese

Manganese, which was one of the mineral nutrients least affected in the soil (Table 2), was the most affected mineral nutrient in aboveground plant parts in response to the fertilization treatments (Table 3). Fertilizing cotton in this soil with $NH_4NO_3$ elevated Mn concentration in all aboveground plant parts. When averaged across the fertilization rates, bulk leaf Mn concentration of the $NH_4NO_3$–fertilized cotton was more than twofold that of the litter-fertilized or the UTC. Similar increases occurred in the other plant parts. Increases of Mn concentration due to litter fertilization, relative to the UTC, were small and insignificant in all plant parts. The elevation of tissue Mn concentration by $NH_4NO_3$ in our research is consistent with research on other crops (Jackson and Carter, 1976; Petrie and Jackson, 1984). These researchers reported that applying ammoniacal fertilizers in bands to soils with suboptimal Mn increased leaf or petiole Mn concentration in barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), and potato (*Solanum tuberosum* L.).

The magnitude of increase of Mn concentration in all plant parts by $NH_4NO_3$ in our research varied with the application rate. Applying the least amount of $NH_4NO_3$–N (34 kg ha$^{-1}$) increased Mn concentration by >100% in leaves and stems and by >50% in reproductive parts relative to the UTC. Applying 90 kg ha$^{-1}$ $NH_4NO_3$–N, which is the local standard N rate, increased Mn concentration by >150% over the UTC. The concentration of Mn in plant parts, overall, increased in direct

Table 2. Concentration of selected mineral elements extracted by Melhich 3 extractant from a silt loam soil fertilized with broiler litter or ammonium nitrate and planted with cotton in northern Mississippi. The analysis was made on soil samples taken from the 0 to 0.15 m depth at the end of the season in 2003 after applying the fertilizers and growing cotton for two consecutive seasons.

| Treatment | Mg | Ca | Na | Mn | Zn | Cu | Fe |
|---|---|---|---|---|---|---|---|
| | mg $kg^{-1}$ | | | | | | |
| UTC† | 77 | 892 | 175 | 272 | 4.1 | 1.10 | 217 |
| Litter, Mg $ha^{-1}$ | | | | | | | |
| 2.2 | 92 | 952 | 180 | 221 | 5.9 | 1.34 | 206 |
| 4.5 | 105 | 996 | 177 | 241 | 4.1 | 1.93 | 199 |
| 5.6 | **114**‡ | 949 | **192** | 174 | **8.5** | 2.08 | **281** |
| 6.7 | **109** | 991 | 186 | 207 | 6.7 | **3.20** | 227 |
| 10.1 | **128** | 992 | **194** | 231 | **11.3** | **3.62** | 261 |
| 13.5 | **130** | 958 | **190** | 210 | **9.3** | **3.4** | 242 |
| $NH_4NO_3$–N, kg $ha^{-1}$ | | | | | | | |
| 34 | 79 | 739 | 177 | 222 | 4.1 | 0.97 | 247 |
| 67 | 88 | 919 | 176 | 232 | 4.0 | 1.13 | 240 |
| 90 | 94 | 944 | 175 | 177 | 6.2 | 1.21 | 252 |
| 112 | 87 | 759 | 180 | 194 | 5.2 | 1.36 | **286** |
| 135 | 78 | 758 | 177 | 258 | 5.3 | 1.00 | 230 |
| 168 | 68 | 713 | 164 | 294 | 4.1 | 1.01 | 220 |
| Average across rates. | | | | | | | |
| Litter | 113 | 973 | 186 | 214 | 7.6 | 2.60 | 236 |
| $NH_4NO_3$ | 82 | 805 | 175 | 229 | 4.8 | 1.11 | 246 |
| CONTRAST | $P > F$ | | | | | | |
| Litter vs. $NH_4NO_3$ | <0.001 | <0.001 | 0.001 | 0.351 | <0.001 | <0.001 | 0.349 |
| ANOVA | | | | | | | |
| Treatment | 0.001 | 0.043 | 0.026 | 0.159 | 0.001 | <0.001 | 0.038 |
| **Significance of linear trend** | | | | | | | |
| Litter | 0.004 | 0.962 | 0.043 | 0.946 | 0.002 | <0.001 | 0.133 |
| $NH_4NO_3$ | 0.294 | 0.259 | 0.165 | 0.075 | 0.807 | 0.996 | 0.443 |
| **Significance of quadratic trend** | | | | | | | |
| Litter | <0.001 | 0.542 | 0.023 | 0.198 | <0.001 | <0.001 | 0.134 |
| $NH_4NO_3$ | 0.131 | 0.144 | 0.196 | 0.007 | 0.551 | 0.918 | 0.106 |

† UTC, unfertilized control.

‡ Means in bold within a column are significantly different from the UTC at $P \leq 0.05$ based on paired *t* test.

proportion to the rate of applied $NH_4NO_3$–N. For example, leaf Mn increased from 156 mg $kg^{-1}$ when not fertilized to a peak of 483 mg $kg^{-1}$ with 135 kg $ha^{-1}$ $NH_4NO_3$–N application. The significant quadratic trend in all plant parts with increasing $NH_4NO_3$–N rate is because of the tendency for Mn concentration to decline with $NH_4NO_3$–N > 135 kg $ha^{-1}$.

In sharp contrast to the effect of $NH_4NO_3$, increasing rates of broiler litter had no or little effect on Mn concentration in plant parts. None of the linear or quadratic trends of Mn concentration in any of the three plant parts in response to applied litter rate were significant (Table 3), suggesting that litter application to this soil did not elevate Mn concentration in aboveground plant parts. Only the highest litter rate of 13.5 Mg $ha^{-1}$ resulted in somewhat elevated Mn concentration in aboveground plant parts, an increase which was only about half that of the highest $NH_4NO_3$–fertilized cotton.

The contrasting effects of the two fertilizer types on Mn concentration in the plant parts may be related to the effects of these fertilizers on soil pH. As reported by Adeli et al. (2010), $NH_4NO_3$ significantly reduced soil pH while litter either maintained or slightly raised the soil pH at the end of the research. Interestingly, there was no clear effect of $NH_4NO_3$ application on soil Mn concentration extracted by Mehlich 3 (Table 2), although Mn concentration in aboveground plant parts was drastically elevated (Table 3) and soil pH as reported by Adeli et al. (2010) was clearly reduced. But this may be an indication that the Mehlich 3 procedure may not be effective in estimating extractable Mn in such soils. Although much less likely, the lack of response of extractable soil Mn to $NH_4NO_3$ while tissue Mn was elevated may also be an indication that extractable Mn was depleted due to plant extraction by the end of the season in 2003 when the soil samples were taken.

Whether Mn nutrition played a major yield-limiting role in this soil is not obvious. Dwarfed plants and crinkle leaf are symptoms of Mn toxicity in cotton (Adams and Wear, 1957). We did not observe such symptoms in our test, but it is possible tissue Mn levels that exceeded the sufficiency range may have been important for lint yield. The sufficiency range of Mn based on the youngest fully expanded leaf (which is the most commonly used cotton plant tissue for nutrient diagnosis)

Table 3. Concentration of selected micronutrients at the flowering stage of cotton fertilized with broiler litter or $NH_4NO_3$–N in northern Mississippi. Each value is an average of four replications pooled across 2002 and 2003.

| Treatment | Leaf | | | | | Stem | | | | | Reproductive | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B† | Mn | Zn | Cu | Fe | B | Mn | Zn | Cu | Fe | B | Mn | Zn | Cu | Fe |
| | mg $kg^{-1}$ | | | | | | | | | | | | | | |
| UTC‡ | 25.0 | 156 | 19.3 | 9.5 | 216 | 10.9 | 22.4 | 13.1 | 7.2 | 26.7 | 20.4 | 84 | 26.0 | 7.8 | 163 |
| Litter, Mg $ha^{-1}$ | | | | | | | | | | | | | | | |
| 2.2 | 27.6 | 191 | 20.1 | 7.8 | 204 | 11.7 | 29.8 | 13.4 | 6.4 | 42.8 | 22.8 | 94 | 26.4 | 8.8 | 232 |
| 4.5 | 23.9 | 120 | 21.3 | 10.3 | 219 | 12.1 | 19.1 | 13.2 | 8.1 | 29.6 | 20.4 | 61 | 27.2 | **9.7**§ | 166 |
| 5.6 | 26.5 | 158 | 21.7 | 8.6 | 187 | **12.9** | 24.5 | 14.7 | 7.4 | 28.4 | 21.6 | 100 | 27.7 | **9.1** | 514 |
| 6.7 | 23.9 | 144 | **21.8** | 9.5 | 234 | **14.0** | 26.4 | 14.8 | 7.0 | 49.1 | 21.3 | 68 | 26.7 | 8.2 | 375 |
| 10.1 | 28.0 | 206 | 21.6 | 9.8 | 238 | **13.8** | 30.8 | 16.4 | 7.7 | 36.0 | 22.8 | 95 | 26.7 | 8.8 | 288 |
| 13.5 | 27.8 | 244 | 20.9 | 9.4 | 223 | **13.3** | 36.7 | 14.7 | 7.5 | 31.4 | 23.4 | 127 | 25.7 | 8.8 | 209 |
| $NH_4NO_3$–N, kg $ha^{-1}$ | | | | | | | | | | | | | | | |
| 34 | 24.9 | 317 | 20.7 | 9.0 | 234 | 11.4 | 44.9 | 13.5 | 6.3 | 43.0 | 20.3 | 109 | 27.3 | **9.3** | 358 |
| 67 | 20.6 | 313 | **21.9** | 9.3 | 218 | 11.8 | 36.7 | 13.0 | 6.5 | 27.2 | 18.4 | 133 | 27.2 | **9.3** | 265 |
| 90 | 22.5 | **414** | **22.7** | 8.9 | 203 | 12.1 | **63.0** | 19.7 | 8.1 | 43.5 | 20.2 | **177** | 28.3 | 8.9 | 360 |
| 112 | 18.9 | **423** | **22.8** | 9.7 | 223 | **13.8** | **69.0** | 20.0 | 7.4 | 37.7 | 20.2 | **195** | 28.8 | 8.6 | 369 |
| 135 | 20.6 | **483** | **22.2** | 9.8 | 198 | **12.6** | **71.6** | 14.0 | 7.4 | 38.4 | 20.4 | **233** | 26.0 | 8.0 | 193 |
| 168 | **20.3** | **445** | **25.8** | 9.9 | 207 | **12.7** | **54.8** | 15.5 | 7.6 | 36.7 | 19.7 | **195** | 26.5 | **9.1** | 468 |
| Average across rates | | | | | | | | | | | | | | | |
| Litter | 26.3 | 177 | 21.3 | 9.2 | 218 | 12.7 | 27.1 | 14.3 | 7.3 | 34.9 | 21.8 | 90 | 26.6 | 8.8 | 278 |
| $NH_4NO_3$ | 21.3 | 399 | 22.7 | 9.4 | 214 | 12.2 | 51.8 | 15.5 | 7.2 | 36.2 | 20.0 | 161 | 27.2 | 8.7 | 311 |
| CONTRAST | $P > F$ | | | | | | | | | | | | | | |
| Litter vs. $NH_4NO_3$ | <0.001 | <0.001 | 0.006 | 0.593 | 0.766 | 0.079 | <0.001 | 0.174 | 0.675 | 0.756 | 0.003 | <0.001 | 0.411 | 0.865 | 0.487 |
| ANOVA | | | | | | | | | | | | | | | |
| Year (Y) | — | 0.416 | 0.439 | 0.013 | 0.007 | — | 0.254 | 0.008 | <0.001 | <0.001 | — | 0.004 | 0.006 | <0.001 | <0.001 |
| Treatment (T) | 0.003 | 0.001 | 0.001 | 0.599 | 0.909 | <0.001 | <0.001 | 0.068 | 0.196 | 0.549 | 0.191 | <0.001 | 0.904 | 0.026 | 0.076 |
| Y × T | — | 0.110 | 0.114 | 0.572 | 0.693 | — | 0.692 | 0.888 | 0.933 | 0.506 | — | 0.825 | 0.517 | 0.537 | 0.079 |
| **Significance of linear trend** | | | | | | | | | | | | | | | |
| Litter | 0.342 | 0.281 | 0.616 | 0.201 | 0.313 | 0.020 | 0.338 | 0.389 | 0.277 | 0.617 | 0.236 | 0.269 | 0.477 | 0.545 | 0.836 |
| $NH_4NO_3$ | 0.067 | 0.041 | <0.001 | 0.216 | 0.323 | 0.033 | 0.071 | 0.432 | 0.044 | 0.902 | 0.831 | 0.006 | 0.523 | 0.228 | 0.643 |
| **Significance of quadratic trend** | | | | | | | | | | | | | | | |
| Litter | 0.365 | 0.369 | 0.100 | 0.841 | 0.910 | <0.001 | 0.376 | 0.467 | 0.636 | 0.655 | 0.207 | 0.319 | 0.549 | 0.393 | 0.374 |
| $NH_4NO_3$ | 0.019 | <0.001 | <0.001 | 0.682 | 0.914 | 0.003 | <0.001 | 0.080 | 0.385 | 0.673 | 0.912 | <0.001 | 0.384 | 0.606 | 0.535 |

† Concentration of B was determined only in 2003.

‡ UTC, unfertilized control.

§ Means in bold within a column are significantly different from the UTC at $P \le 0.05$ based on paired *t* test.

at the flowering stage ranges from as low as 25 mg $kg^{-1}$ to as high as 350 mg $kg^{-1}$ (Mitchell and Baker, 2000). Bulk leaf Mn concentration in our research exceeded 400 mg $kg^{-1}$ for cotton fertilized with the recommended $NH_4NO_3$–N rate for optimum yield and reached as high as 483 mg $kg^{-1}$ when the applied $NH_4NO_3$–N exceeded the recommended 90 kg $ha^{-1}$ (Table 3). Bulk leaf Mn concentration never exceeded 244 mg $kg^{-1}$ when the cotton was fertilized with any amount of litter. Cotton produced as much as 1161 kg $ha^{-1}$ lint when fertilized with broiler litter but never exceed 1066 kg $ha^{-1}$ lint when fertilized with any of the $NH_4NO_3$–N rates (Tewolde et al., 2010). The inability of the $NH_4NO_3$–fertilized cotton to produce as much lint yield as the litter-fertilized cotton in this soil may be related to Mn concentration in aboveground plant parts. The highest yielding $NH_4NO_3$–N rate of 90 kg $ha^{-1}$ had 414 mg $kg^{-1}$ bulk leaf Mn concentration compared to only 144 mg $kg^{-1}$ bulk leaf Mn concentration of the highest yielding 6.7 Mg $ha^{-1}$ litter rate (Table 3, Tewolde et al., 2010). These results indicate that bulk leaf Mn concentration as high as 400 mg $kg^{-1}$ may not be desirable for optimum lint production and that applying soil-acidifying fertilizers to such marginal upland soils must be avoided, unless accompanied by the application of liming materials. The results also show that litter is a preferred fertilizer for cotton over the inorganic $NH_4NO_3$ in this soil with marginal pH because fertilizing with litter maintained a more ideal soil pH without applying liming materials and resulted in greater lint yield than fertilizing with $NH_4NO_3$.

### Potassium

When pooled across the application rates, leaf K concentration, but not stem or reproductive K concentration, was

**Table 4. Concentration of selected primary and secondary nutrients at the flowering stage of cotton fertilized with broiler litter or $NH_4NO_3$–N in northern Mississippi. Each value is an average of four replications pooled across 2002 and 2003.**

| | Leaf | | | | | Stem | | | | | Reproductive | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | P | K | Mg | Ca | Na | P | K | Mg | Ca | Na | P | K | Mg | Ca | Na |
| | g kg$^{-1}$ | | | | | | | | | | | | | | |
| UTC† | 4.17 | 26.0 | 3.51 | 32.2 | 0.87 | 2.39 | 21.0 | 1.91 | 6.63 | 0.70 | 6.40 | 22.9 | 4.09 | 14.4 | 0.65 |
| Litter, Mg ha$^{-1}$ | | | | | | | | | | | | | | | |
| 2.2 | 3.86 | 27.5 | 3.88 | 30.9 | 0.93 | 2.30 | 20.6 | 1.92 | 6.37 | 0.68 | 6.3 | 24.5 | **4.42** | 13.6 | 0.66 |
| 4.5 | 3.89 | 28.2 | **4.42** | 34.1 | 1.05 | 2.34 | 22.9 | 2.07 | 6.85 | 0.75 | 6.3 | 23.8 | 4.12 | 14.6 | 0.7 |
| 5.6 | 3.93 | **30.3‡** | **4.21** | 30.1 | **1.01** | 2.30 | 23.3 | 2.08 | 6.11 | 0.72 | 6.2 | 24.1 | 4.22 | 13.3 | 0.69 |
| 6.7 | 4.01 | **32.0** | **4.42** | 30.7 | **1.08** | 2.34 | **25.9** | 2.24 | 6.96 | 0.78 | 6.2 | 24.8 | 4.12 | 13.4 | 0.65 |
| 10.1 | 3.76 | **31.7** | **4.39** | 32.5 | **1.05** | 2.32 | **25.6** | **2.40** | 7.13 | 0.81 | 6.1 | 23.7 | 3.88 | 13.8 | 0.70 |
| 13.5 | 3.64 | **31.3** | **4.73** | 30.3 | **1.07** | 2.07 | **25.5** | **2.35** | 6.51 | 0.78 | 6.0 | 24.6 | 4.06 | 13.4 | 0.69 |
| $NH_4NO_3$–N, kg ha$^{-1}$ | | | | | | | | | | | | | | | |
| 34 | 3.93 | 28.9 | **3.95** | 32.1 | 0.9 | 2.13 | 21.7 | 2.12 | 6.61 | 0.71 | 6.2 | 23.7 | 4.3 | 14.2 | 0.69 |
| 67 | 3.92 | **30.3** | **3.96** | 33.0 | 0.94 | 2.27 | 24.2 | 2.12 | 6.92 | 0.68 | 6.3 | 24.3 | 3.98 | 13.9 | 0.68 |
| 90 | 3.89 | **29.3** | **4.22** | 30.7 | 0.94 | 2.24 | **25.0** | **2.34** | 6.93 | 0.73 | 6.2 | 24.1 | 3.98 | 13.6 | 0.65 |
| 112 | 3.75 | **29.2** | **3.94** | 31.4 | 0.87 | 2.25 | **26.8** | **2.49** | **7.61** | 0.74 | 6.1 | 24.2 | 3.86 | 14.2 | 0.69 |
| 135 | 3.76 | 27.9 | **4.61** | 32.3 | 0.97 | 2.02 | 24.2 | **2.37** | 6.91 | 0.71 | 6.0 | 23.6 | 4.00 | 14.0 | 0.69 |
| 168 | 3.90 | 27.0 | **4.68** | 35.3 | **0.99** | 2.18 | **24.8** | **2.51** | **7.76** | 0.71 | 6.1 | 24.0 | 3.8 | 14.7 | 0.73 |
| Average across rates | | | | | | | | | | | | | | | |
| Litter | 3.85 | 30.2 | 4.34 | 31.4 | 1.03 | 2.30 | 23.5 | 2.14 | 6.65 | 0.74 | 6.2 | 24.0 | 4.13 | 13.8 | 0.68 |
| $NH_4NO_3$ | 3.86 | 28.8 | 4.23 | 32.5 | 0.93 | 2.21 | 24.0 | 2.27 | 7.05 | 0.71 | 6.2 | 23.8 | 4.00 | 14.1 | 0.69 |
| CONTRAST | $P > F$ | | | | | | | | | | | | | | |
| Litter vs. $NH_4NO_3$ | 0.917 | 0.038 | 0.201 | 0.111 | <0.001 | 0.078 | 0.472 | 0.035 | 0.010 | 0.058 | 0.606 | 0.335 | 0.025 | 0.102 | 0.530 |
| ANOVA | | | | | | | | | | | | | | | |
| Year (Y) | 0.012 | 0.041 | 0.014 | 0.021 | 0.076 | <0.001 | 0.001 | <0.001 | 0.701 | 0.002 | <0.001 | 0.633 | <0.001 | <0.001 | 0.001 |
| Treatment (T) | 0.879 | 0.011 | <0.001 | 0.079 | 0.002 | 0.088 | 0.002 | <0.001 | 0.001 | 0.184 | 0.515 | 0.105 | 0.010 | 0.135 | 0.709 |
| Y × T | 0.073 | 0.494 | 0.045 | 0.507 | 0.489 | 0.041 | 0.159 | 0.265 | 0.023 | 0.864 | 0.419 | 0.647 | 0.832 | 0.074 | 0.228 |
| **Significance of linear trend** | | | | | | | | | | | | | | | |
| Litter | 0.207 | 0.008 | 0.002 | 0.578 | 0.045 | 0.072 | 0.006 | 0.002 | 0.461 | 0.010 | 0.055 | 0.892 | 0.009 | 0.422 | 0.599 |
| $NH_4NO_3$ | 0.604 | 0.094 | <0.001 | 0.138 | 0.199 | 0.646 | 0.104 | 0.006 | 0.011 | 0.755 | 0.178 | 0.946 | 0.005 | 0.359 | 0.29 |
| **Significance of quadratic trend** | | | | | | | | | | | | | | | |
| Litter | 0.223 | <0.001 | 0.002 | 0.694 | 0.006 | 0.162 | 0.001 | 0.003 | 0.682 | 0.168 | 0.216 | 0.117 | 0.472 | 0.678 | 0.901 |
| $NH_4NO_3$ | 0.288 | 0.020 | 0.003 | 0.082 | 0.343 | 0.368 | 0.005 | 0.001 | 0.009 | 0.907 | 0.279 | 0.088 | 0.232 | 0.635 | 0.725 |

† UTC, unfertilized control.

‡ Means in bold within a column are significantly different from the UTC at $P \le 0.05$ based on paired **t** test.

affected significantly by fertilizer type (Table 4). Fertilizing with litter slightly (≈5%) but significantly increased bulk leaf K concentration over fertilizing with $NH_4NO_3$ or the UTC. Cotton fertilized with $NH_4NO_3$ had about the same stem or reproductive K concentration as cotton fertilized with litter.

Increasing rates of either fertilizer type affected K concentration in bulk plant parts. Among the $NH_4NO_3$–N rates, bulk leaf K concentration was highest at 30.3 g kg$^{-1}$ when the cotton was fertilized with 67 kg ha$^{-1}$ $NH_4NO_3$–N and declined progressively with additional $NH_4NO_3$ application to as low as 27 g kg$^{-1}$ with the highest rate of $NH_4NO_3$–N application (Table 4). Interestingly, the 67 kg ha$^{-1}$ $NH_4NO_3$–N rate which resulted in the highest leaf K concentration did not produce the highest lint yield (Tewolde et al., 2010). Applying 90 kg ha$^{-1}$ $NH_4NO_3$–N produced the highest lint yield but not the highest leaf K concentration among the $NH_4NO_3$–fertilized treatments. The change in leaf K with increasing $NH_4NO_3$–N application was not due to applied K because all $NH_4NO_3$ treatments received the same blanket rate of K every year based on local recommendations. Unlike leaf K, stem K concentration increased with increasing $NH_4NO_3$–N application to as high as 26.8 g kg$^{-1}$ with 112 kg ha$^{-1}$ $NH_4NO_3$–N application (Table 4). Reproductive K concentration showed no clear trend with increasing rate of $NH_4NO_3$–N application.

Both leaf and stem K concentration of the litter-fertilized cotton increased with increasing litter rate to as high as 32.0 g kg$^{-1}$ in leaves and 25.9 g kg$^{-1}$ in stems with 6.7 Mg ha$^{-1}$ litter application (Table 4). This application rate (6.7 Mg ha$^{-1}$), which resulted in the highest bulk leaf and stem K concentration, also produced the peak lint yield (Tewolde et al., 2010). Increasing the litter rate beyond the 6.7 Mg ha$^{-1}$ to as high as 13.5 Mg ha$^{-1}$ did not further increase leaf or stem K. The increase of leaf and stem K with increasing litter application rate may be directly related to the increasing amount of litter-derived K. Applied litter-derived K increased from an average of 61 kg $ha^{-1}$ $yr^{-1}$ for the 2.2 Mg $ha^{-1}$ rate to 377 kg $ha^{-1}$ $yr^{-1}$ for the 13.5 Mg $ha^{-1}$ litter rate (Table 1). Increasing the rate of applied litter rate from 2.2 to 13.5 Mg $ha^{-1}$ did not affect reproductive K concentration.

Similar to Mn nutrition, K nutrition may have played a role in the lint yield difference between litter- and $NH_4NO_3$–fertilizations. The highest yielding litter rate of 6.7 Mg $ha^{-1}$ (Tewolde et al., 2010) had 32.0 g $kg^{-1}$ bulk leaf K compared with 29.3 g $kg^{-1}$ for the highest yielding $NH_4NO_3$–N rate of 90 kg $ha^{-1}$ (Table 4). These results suggest that the less peak lint yield of the $NH_4NO_3$–fertilized cotton (1066 kg $ha^{-1}$) than the peak lint yield of the litter-fertilized cotton (1161 kg $ha^{-1}$) may be related to this difference in leaf K.

## Phosphorus, Calcium, Magnesium, and Sodium

When averaged across rates, there were no clear differences in bulk leaf P, Ca, or Mg concentration between $NH_4NO_3$–fertilized cotton and litter-fertilized cotton (Table 4). This lack of difference suggests the yield differences between $NH_4NO_3$–fertilized and litter-fertilized cotton may not be directly attributable to the nutrition of P, Ca, or Mg. The fertilizer type affected concentrations of these nutrients more in stems than in leaves or reproductive parts. Stem Mg and Ca in particular were greater in $NH_4NO_3$–fertilized than litter-fertilized cotton. The implication of these differences on lint yield, however, is not obvious. Leaf Na concentration was clearly greater in litter-fertilized than in $NH_4NO_3$–fertilized cotton, but it is unlikely the yield increasing effect of litter is related to the greater tissue Na level.

Increasing the rates of both fertilizers affected concentration of Mg and P in the plant parts. Magnesium concentration in leaves and stems increased with increasing rate of applied $NH_4NO_3$–N or broiler litter with little or no difference between the trends of the two fertilizer types (Table 4). Concentration of P in leaves, stems, and reproductive parts seemed to decline slightly with increasing rate of both $NH_4NO_3$–N and litter but this declining trend was not significant. The change in leaf Ca concentration with increasing rates of litter or $NH_4NO_3$–N showed no clear trend. Only the highest $NH_4NO_3$–N rate of 168 kg $ha^{-1}$ seemed to increase leaf Ca concentration.

## Boron, Zinc, Iron, and Copper

Concentration of B in all plant parts was affected by fertilizer type and also by the rate of each fertilizer. When pooled across the rates, applying litter resulted in greater B concentration than applying $NH_4NO_3$ in all plant parts (Table 3). The response of leaf B to the rate of each fertilizer was also distinctly different. While leaf B showed a tendency to increase or remain the same with increasing applied litter rate, it declined with increasing applied $NH_4NO_3$–N rate. The lack of leaf B response to litter rate suggests the greater average leaf B in litter-fertilized cotton than $NH_4NO_3$–fertilized cotton may not be because litter supplied additional B, considering that <0.6 kg $ha^{-1}$ B was applied by any of the litter rates (Table 1), but because applying $NH_4NO_3$ reduced B uptake. Stem B concentration increased with increasing rate of either fertilizer to a peak at 6.7 Mg $ha^{-1}$ litter and 112 kg $ha^{-1}$ $NH_4NO_3$–N. Boron concentration in reproductive parts was not affected by the rate of either fertilizer. The greater B concentration in plant parts of the litter-fertilized cotton than $NH_4NO_3$–fertilized cotton in this soil suggests that B may have been another nutrient that may have contributed to the better yield performance of the litter-fertilized cotton.

Extractable soil Zn and Cu greatly differed between the two fertilizers, but this difference was not reflected in the concentration of these micronutrients in aboveground plant parts. Applying litter increased soil Zn by about 59% and soil Cu by 134% relative to applying $NH_4NO_3$ (Table 2). But there was no such increase in the concentration of these micronutrients in aboveground plant parts when averaged across the respective fertilizer rates. Actually, leaf Zn was reduced and stem Zn and reproductive Zn were not affected by litter relative to $NH_4NO_3$ (Table 3). Although soil Zn and Cu increased in almost direct proportion to applied litter, this availability had little or no effect on the concentration of the nutrients in aboveground plant parts. Concentration of Fe in any of the plant parts was not affected by the type or rate of fertilizer (Table 3). Overall the results suggest that none of the micronutrients Zn, Cu, or Fe may have contributed to the better yield performance of the litter-fertilized cotton relative to the $NH_4NO_3$–fertilized cotton.

The results overall show that fertilizing cotton with poultry litter in this marginally productive upland soil is preferred to the conventional $NH_4NO_3$ fertilizer. As reported previously, fertilizing with even the smallest amount of $NH_4NO_3$–N affected cotton yield (Tewolde et al., 2010) by reducing the soil pH (Adeli et al., 2010), elevating plant Mn concentration, and possibly by altering other soil properties. Exceeding the $NH_4NO_3$–N rate required for optimum lint yield further exacerbated the problem of elevated plant Mn and low pH in addition to being wasteful. Applying lime most likely would have prevented the lowering of soil pH brought about by fertilizing with the synthetic $NH_4NO_3$ fertilizer, but our results clearly show that fertilizing with litter would make liming an unnecessary additional step for a more profitable cotton production in this soil with marginal soil pH and productivity. Fertilizing with broiler litter maintained or increased the pH of this soil as reported previously (Adeli et al., 2010) and prevented elevation of Mn concentration in aboveground plant parts as was the case with $NH_4NO_3$–fertilized soil. Many farmers, crop consultants, extension experts, and other practitioners wonder and ask whether litter can correct soil pH. Several studies have shown that litter maintains or increases (Hue, 1992; Kingery et al., 1994; Reddy et al., 2008) soil pH but these increases are slow and gradual and may not be immediate enough for many farmers. Our results show that litter, unlike the synthetic fertilizer $NH_4NO_3$ which suppressed cotton yield relative to litter, maintained soil chemical and physical conditions ideal for optimal cotton mineral nutrition and lint yield in this upland soil.

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